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# Automated Optical Extraction from Line Arrays of the Alignment between Microfabricated Layers

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## Abstract

**Machine reading of layer alignment from line arrays in fully fabricated wafers is demonstrated. Misalignment is calculated from the correlation function of optical intensity scans through arrays in the two test layers. For 2-urn metal lines and *grooves* in a garnet substrate the measurement error was * 0.21 υm.**

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The development of the alignment extraction procedure was precipitated by the need to verify the alignment of conventional microelectronic structures, such as metal lines, and micromechanic structures, such as grooves in micromagnetic devices *on* garnet **substrates. Because** of the nonconducting nature of the substrate, electrical methods were ruled out. Available optical test structures of the vernier or wedge type had the disadvantage of requiring a human reader additionally burdened by poor contrast of shallow grooves. Yield arrays of metal lines and grooves also often showed rough edges, which would make a reading of a rather localized conventional alignment test structure even more difficult. However, the rather good average definition of the line arrays gave rise to the general idea to utilize pairs of such arrays for alignment measurement. Any misalignment between the **two** involved layers perpendicular to the lines would be detected as a phase shift between two periodic space signals, This method would also lead to an easy method of recognition by a machine in an automated system,

Figure 1 (a) shows the first implementation of two line' arrays in close proximity, but not overlapping. An intensity scan of the image perpendicular to the lines yields maxima in the region of the lines stemming from light reflected by a metal line or groove edges. Let the ***scan over*** Array 1 produce an intensity sequence $a(i)$ and the scan over Array 2 a sequence $b(i)$, then the correlation function

[1] We may talk of stripes rather than lines when we want to emphasize the finite width.

$$c(j) = \sum_i a(i)b(i + j - 1) \tag{1}$$

should yield maxima when the two arrays are in perfect alignment. The positional of the first maximum gives the total shift $(j_1 - 1)$ of Array 2 with respect to Array 1 (in pixels). The difference between the position $j_2$ of the second maximum and the position of the first one gives the pitch $p_j$, in pixels, common to both arrays. With a pitch $p$ in real length, the real relative shift $s$ becomes

$$s = (j_1 - 1)p/p_j. \tag{2}$$

If the relative shift contains an intentionally designed shift $s_d$, e.g., equal to $p/2$, the misalignment caused by the fabrication process will be

$$m = s - s_d. \tag{3}$$

This procedure requires that the scan direction is sufficiently perpendicular to the lines such that a shift introduced by the nonorthogonality is sufficiently less than one pixel.

A second method, which drops that requirement, starts with a partly interdigitated layout, shown in Fig. 1 (b). For the first scan the isolated array with the clearer definition is chosen, The second scan is taken through the region where both arrays interdigitate. The correlation function is calculated similarly to the first case except for allowing a shift to the left ≤ $h$ in the initial maximum due to nonorthogonality of the scans. This initial maximum, caused by the correlation of both signals from the first array is nominally expected at $j_1 = l + h$. The second maximum, caused by the correlation of the signal from the first array with that of the second one, is nominally expected at $j_2 = p_j/2 + l + h$. The third maximum comes again from the correlation of the signals from the first array and is nominally expected at j = $p_j + l + h$. The real shift of Array 2 with respect to Array 1 is

$$s = (j_2 - j_1)p/(j_3 - j_1). \tag{4}$$

With $s_d$ = p/2 the misalignment becomes

$$m = s - p/2. \tag{5}$$

## Results

Figure 2 shows an image for a case which constituted the greatest challenge because of the dissimilarity of the signals from the two arrays. Array 1 was the first metal of a IiR-off gold process whereas Array 2 was a O. S-urn deep groove in the garnet substrate covered by an Al mirror. The arrays consist both of thirteen nominally 2-pm wide lines with 8-µm pitches. The nominal shift between the arrays is 4 µm. The 640 pixel x 480 pixel image was taken with a video camera mounted on a metallurgic microscope. Care was taken to align the lines of the arrays to the frame in order to demonstrate both methods although the structure had no directly neighbored parts of the isolated regions. Three scans were taken: The first at row 133 through the isolated metal array, the second at row 164 through the interdigitated region, and the third at *row* 377 through the isolated groove array, see Fig. 3 (a), (b), and (c). The interdigitated 164-scan has the reflections from the stripes barely separated.

It is for cases somewhat worse then this that the first method is recommended because it deals with more clearly separated signals. The result of the correlation between the isolated signals 133 and 377 is shown in Fig. 4 (a). Well defined maxima are exhibited with $j_1 - 1 = 15$ and $p_j = j_2 - j_1 = 31$. As $s_d = p/2$ and $p = 8$ µm, the misalignment becomes with Eqs. (2) and (3):

$$m = (-0.13 * 0.21) \text{ pm}. \quad (6)$$

The result of the correlation using the second method (with $h = 3$) is shown in Fig. 4 (b). Besides the main maxima at $j_1 = 4$ and $j_3 = 35$, a satellite maximum has developed at $j_2 = 19$, stemming from the correlation of the signal from Array 1 with that of Array 2. With Eqs. (4) and (5), a misalignment identical to that obtained in Eq. (6) is calculated. This shows that the alignment of the imaged lines to the image frame was indeed achieved.

Attempts were made to directly verify these results in the following ways:

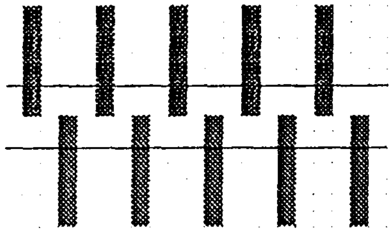
1. A cut, shift and paste method directly on the image verified the result of the numerical procedure quantitatively.

**2.** A method fitting a series of Lorentzian profiles to the individual scans, see Figs. 4 and 5, gave a misalignment of ***m*** = @.4&0.4) urn, a result compatible with the other results but with about twice the error.

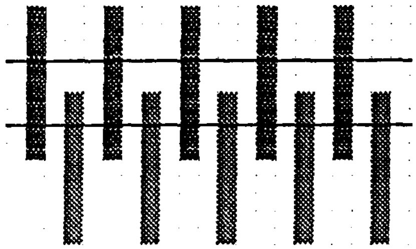
In conclusion, it has been demonstrated that the alignment between microfabricated layers in a 2-urn process can be extracted automatically from line arrays with an error of less than half the specified fabrication tolerance of 0.5 μm. In further improvements to the extraction method, noise in the signals maybe improved by averaging over several pixels in the direction parallel to the stripes, and spatial resolution of the correlation function may be enhanced by finding the maxima of a splined or fitted function.

## Acknowledgments

Matt Natale took the microscopic image of the test structure. Thanks *to* Li-Jen Cheng for providing the image scans and discussions on image processing. Ziad Haddad proposed Type 2 of the test structure based on an analogy to the RADAR problem, first suggested by David Opalsky. George Patterson suggested the potential improvements.



(a)



(b)

Figure 1: Alignment test structures designed with stripe widths w, pitches p = 4w, line numbers n = 5, and a shift&j= 2w. Horizontal lines: intensity scans. (a) First type: Arrays butting. (b) Second type: Arrays **interdigitated.**

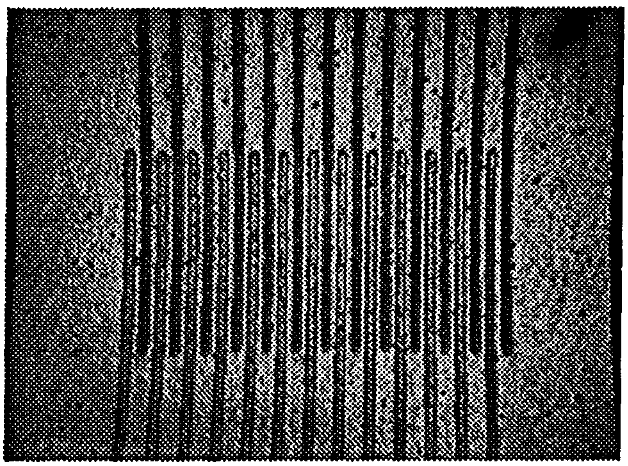
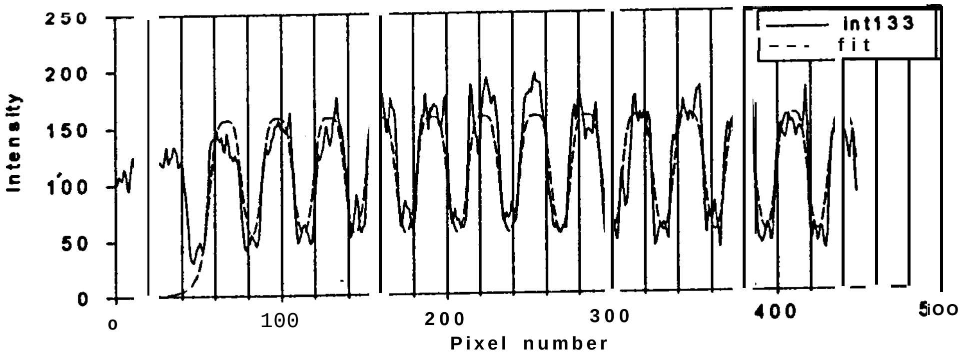
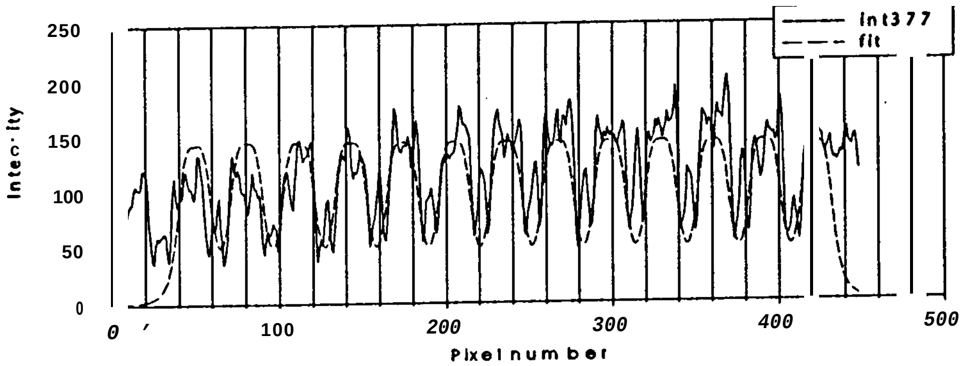


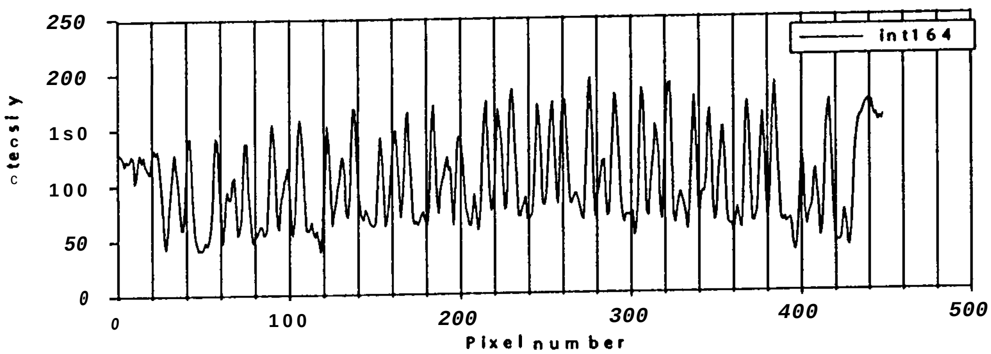
Figure 2: Image of alignment **test** structure with gold **metal** array (top) and aluminized groove **in** garnet **array(bottom).** Nominal **linewidths** are 2 urn, line numbers **are** 13. Pixel rows are counted top (1) to bottom (480). Scans are taken at row 133 through the metal array, at row 164 through the **interdigitated** region, and at row 377 through the groove array.




(a)

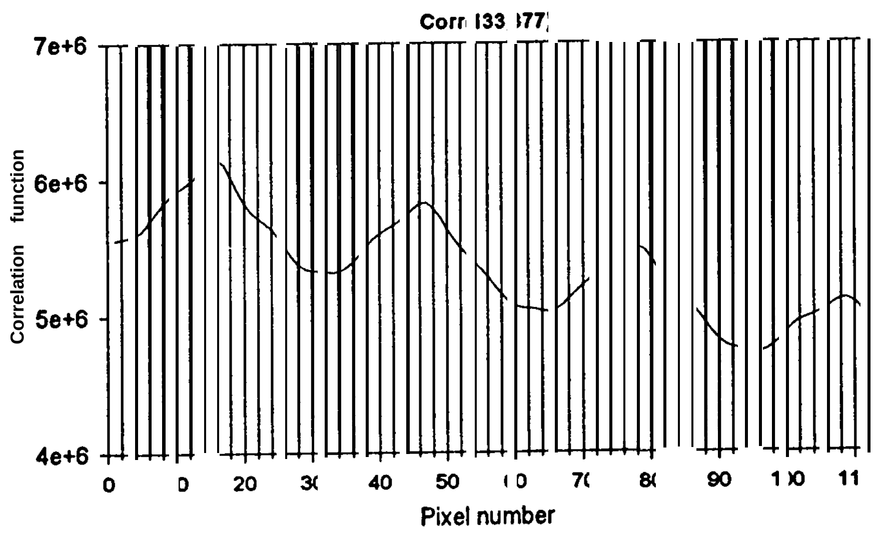



(b)




(c)

Figure 3: Intensity scans and fits by series of Lorentzians through (a) metal array at row 133, (b) groove array at row 377, (c) interdigitated region of arrays at row 164



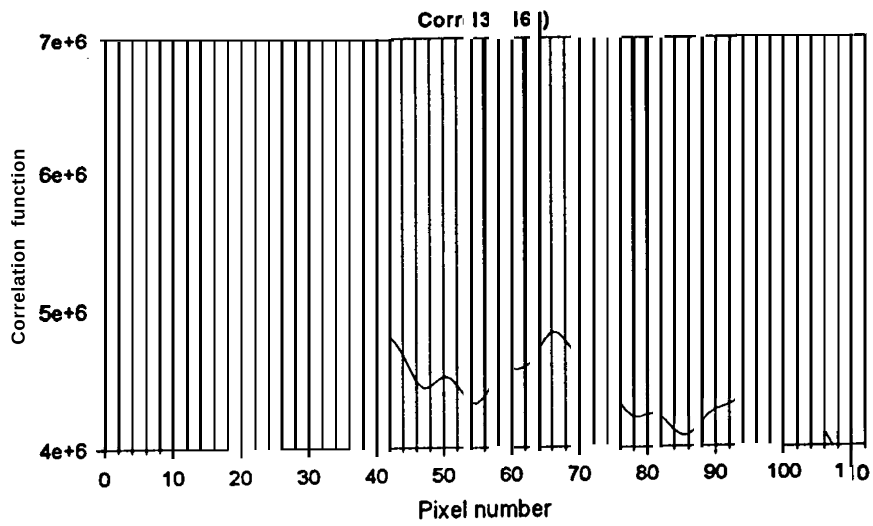




Figure 4: Initial part of correlation function of (a) rows 133 (metal array) and 377 (groove array) for first misalignment extraction method and of (b) rows 133 (metal array) and 164 (interdigitated region) for second misalignment extraction method with shift parameter h = 3.